Hawley & Krahl

Strength of Concrete

Civil Engineering
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STRENGTH OF CONCRETE

WITH

DIFFERENT PROPORTIONS OF THE VOIDS FILLED

BY

WILLIAM ALBERT HAWLEY
AND
BENJAMIN FRANKLIN KRAHL

THESIS

FOR DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

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William Albert Hawley and Benjamin Franklin Krahl

ENTITLED Strength of Concrete with Different Proportions of the Voids Filled

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STRENGTH OF CONCRETE
WITH
DIFFERENT PROPORTIONS
OF THE
VOIDS FILLED.

INTRODUCTION.

Many experiments have been made to determine the strength of concrete, but in the majority of cases the tests were made with proportions of the ingredients varying with the volume of the aggregate, rather than with the per cent of voids in it. The results are of course variable, due to the different conditions, but as a rule determine which of the proportions tested is the best. Apparently in the opinion of those making the experiments, that is the way to make the tests, and hence no other methods have been investigated.

The writers beleive that concrete

should be proportioned with respect to the voids in the aggregate. To make good concrete each piece of the aggregate should be covered with a thin layer of mortar, and the mass should not be porous. In two kinds of broken stone having the same volume, the voids in the one may be much greater than in the other. If such is the case, it is plainly evident that to get the same strength, one must contain more mortar than the other.

The object of this investigation is to determine the relation existing between the strength of concrete and the per cent of voids filled.

Both the crushing and transverse strengths were investigated. To make an exhaustive study of this question, a great deal of time would be required, much more in fact than could be given under the circumstances. It is beleived, however, that if the systems followed were carried to greater completeness, the results

would be very valuable, and well worth the time spent upon them.

Mr. G. F. Beckerleg*, of the class of '99, investigated this subject somewhat; and although his results are far from satisfactory, the writers derived much benefit from his work. We were able to see wherein he made mistakes, and could profit by his experience. In the first place he undertook such a great amount of work that he was unable to do justice to the subject, and his results lacked completeness. He introduced one very objectionable element, which, although it gives a valuable result in itself, prevents a comparison between his several results. In making his cubes containing mortar equal to 100 and 75 per cent of the voids, he used a certain size of broken stone, having a given amount of voids; while in the cubes containing 50 per cent of mortar, he used a finer broken stone, which of

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course had a different proportion of voids.

Mr. Beckerleg's cubes were stored in a steam heated room from the time they were made until broken; and the heat may have evaporated the water to such an extent as to seriously weaken his cubes. It is certain that some element of variation did exist, as his cubes were stronger at 30 days than at 90 and 180 days. He concluded that the strength of the concrete decreased more rapidly than the per cent of voids left unfilled.

To make certain of completing the investigation in the time available, the writers decided to use but one brand of cement, and one kind of sand and broken stone. We decided that the cement should be of some standard brand, so that the results would be of general interest. Alpha American Portland cement was chosen as fulfilling

as nearly as possible the above condition.

The concrete was first made with an amount of mortar exactly equal to the voids in the aggregate. In order to determine what effect the increasing or decreasing of this amount would have upon the strength of the concrete, mortar equal to 125 and 75 per cent of the voids was also used. Thus we had three kinds of concretes, made by filling 125, 100, and 75 per cent of the voids with mortar. The effect of these proportions was investigated both for crushing and transverse strength. For the crushing strength, the specimens tested were six-inch cubes, and for the transverse strength, bars, 6 × 6 × 18 inches. The tests consisted of breaking 3 cubes and 2 bars of each proportion at the age of 7, 30, and 90 days.

THE MATERIALS.

Sand. In these experiments clean sharp sand was used. It consisted mainly of silica, with a small amount of quartz. The fineness is shown in Table I.

TABLE I. FINENESS OF SAND.

Sieve No.	Per Cent		Total Per Cent	
	Caught	Passing	Caught	Passing
20	39.74	——	39.74	60.26
30	16.90	——	56.64	43.36
50	17.42	——	74.06	25.94
75	20.18	05.60	94.24	05.60

The voids in the sand were determined when thoroughly rammed. The following method was used: a measured amount of water was placed in a pail whose capacity was known. the sand was then poured into the pail, and allowed to fall through the water, thus eliminating any

errors which might arise from imprisoned air bubbles. If the water had been poured into the sand, some of the air confined in the sand might have remained, and the exact per cent of the voids would not have been determined. When the pail was full, the water and the sand were both at the level of the top of the pail. The volume of the voids in the sand is then equal to the amount of water that has been put into the pail. The per cent of voids is equal to the volume of the pail, which is the amount of sand used, divided into the amount of water used.

Two determinations of the amount of the voids were made, each giving 29%. To make round numbers in the measuring of quantities, the voids were assumed as $33\frac{1}{3}$%, and a mixture of 1 part cement, to 3 parts sand, used as a mortar.

By this method the voids of the sand are not exactly filled, as we used 1 part loose cement to 3 parts loose sand, which is equivalent to filling about $\frac{8}{10}$ of the voids in the rammed sand. However, this does not materially affect the results as the same proportions were used throughout the tests, and only relative results are sought.

Stone. The aggregate was broken limestone from a quarry at Kankakee, Illinois. It was unscreened, and broken to pass a two-inch ring. The voids in the rammed stone were determined in the same manner as for the sand. Three determinations gave 42, 37, and 38 per cent. 40 per cent was taken as the amount of voids, and all measurements based on that ratio.

Cement. Alpha American Portland cement was used throughout the tests. It was all taken

from the same barrel, so that it was probably of uniform grade.

The fineness is shown by Table II.

TABLE II. FINENESS OF CEMENT.

Sieve No.	Per Cent		Total Per Cent	
	Caught	Passing	Caught	Passing
50	0.3	—	0.3	99.7
74	4.2	—	4.5	95.5
100	9.6	—	14.1	85.9
173	18.0	68.0	32.1	68.0

Tests for soundness proved the cement to be of a good quality. The weight of the cement was 88 pounds per cu. ft., or 109.1 pounds per bu. The weight was determined by sifting the cement, and allowing it to fall 3 feet into a box whose capacity was known.

The 7-day test for tensile strength of neat cement gave an average of 635 lb. per sq. in. for plastic mortar, and 686 lb. per sq. in. for dry mortar. When

mixed with sand in the proportion of 1 to 3, the tensile strength for briquettes 7 days old was 262 lb.

THE APPARATUS.

The apparatus used consisted of a mixing-box, hoe, tamper, and molds.

Mixing Box. This consisted of a frame of six-inch boards, fitting the top of a slate table 30 × 48 inches.

Tamper. This was of cast-iron, weighing 9 pounds, with handle. The base measured 3×3 inches, giving an area equal to one quarter of the section of a cube. The handle was a 1½ inch, round pipe, 36 inches long.

Molds. The molds for the cubes were in gangs of three, and were made of two-inch oak plank, bolted together in such a way as to be removed without injuring the cubes. The interior dimensions were 6×6×6 inches.

The same molds were used for the bars, by removing the

interior partitions and filling the grooves in the sides with strips, thus making the sides of the molds continuous from end to end. The interior dimensions were 6 × 6 × 22 inches.

The molds were all new, thus giving the cubes and bars smooth side surfaces.

MAKING THE CUBES.

Proportioning The sand and cement were thoroughly mixed dry, in the proportion of 1 part cement to 3 parts sand, and in a sufficient quantity to make a complete set of cubes or bars at one time. By this method a mortar was obtained which did not vary in consistency.

In proportioning the materials for the concrete, the standard of measurement used was a cylindrical galvanized-iron can, about 8 inches in diameter, and 30 inches in height.

A quantity of broken stone, sufficient to make three cubes, or one bar, was placed in this can and the top of the same plainly marked on the side of the can. 40 per cent of this height was then marked, as the per cent of voids in the broken stone. 125 and 75

per cent of the latter height was then marked in the same manner. These three marks indicate the top-level of the quantity of sand and cement neccessary to fill 75, 100, and 125 per cent of the voids of the broken stone.

Mixing. Having taken the proper quantity of sand and cement, mixed as stated above, a sufficient quantity of water was added to make a plastic mortar. The stone, having previously been dampened but containing no loose water, was then added; and the whole mass was thoroughly mixed with trowels and hoe, until each particle of stone was covered with a thin layer of mortar.

Molding. The concrete was placed in the molds in layers of 1½ to 2 inches, and thoroughly tamped, care being taken to always tamp in the same manner, and with the same force. The concrete

was of such consistency that when tamped, water would rise to the surface in thin layers. When the molds had been filled, the top surface was trowelled off, to give a smooth bearing surface for the testing machine.

Storing. After molding, the concrete was covered with damp cloths for 48 hours, when the molds were removed, and the cubes and bars stored under water until the time for breaking.

BREAKING.

For breaking the cubes a 100,000-pound Riehle machine was used, in which the pressure was supplied by an oil pump. The cubes were placed directly on the bed of the machine, and carefully centered. A cast-iron plate 10×10×2 inches was placed on top of the cubes. Between this plate and the top bed of the machine was placed a self-adjusting plate, which insured the line of pressure being perpendicular to the top of the cube.

The bearing surfaces of the cubes were the top and bottom as molded. No cushions were used in applying the pressure to the cubes. The pressure was applied at a uniform rate until failure occurred. The first sign of failure was a shower of dust falling from the sides. Vertical cracks then appeared, which

gradually widened out, and the sides split off, in the usual form of pyramidal fracture of a crushed cube.

The bars were broken in a 200,000-pound Olsen machine, in which the pressure was applied by gearing.

The supports were rounded knife-edges, and were placed 18 inches apart, the load being applied midway between these. Care was taken that the supports and line of application of the force were perpendicular to the longitudinal axis of the bar.

The pressure was applied very slowly until failure. The failure took place suddenly, in the form of a crack directly under the line of application of the force.

The tensile stress in the lower fibres was obtained by the formula $S = \frac{Mc}{I}$, where M = the bending moment, $c = \frac{1}{2}$ the depth of the beam, and I = the moment of inertia. With a

beam 18 inches between supports, and 6×6 inches cross section, this reduces to the form $S = \frac{1}{8} W$, where W = the breaking load.

The results of this investigation have been tabulated, and are shown in the following tables. Table III shows the crushing strength of the cubes, and their unit strength; Table IV shows the transverse strength, and the modulus of rupture. Table V is a comparison of results. It gives the strength of the concrete in per cent of the strength of that, in which 100 per cent of the voids are filled with mortar. Tables VI gives the relative cost of concrete, proportioned as in these experiments.

TABLE III

CRUSHING STRENGTH OF 6-INCH CUBES

Age	Per Cent of Voids Filled with Mortar					
	125		100		75	
	Crushing Strength		Crushing Strength		Crushing Strength	
	Total	Lbs. per Sq. in	Total	Lbs. per Sq. in.	Total	Lbs. per Sq. in.
7 Days	52100	1447	42480	1180	31010	861
	56730	1576	45690	1269	31940	887
	62200	1728	50280	1397	33390	927
mean	57010	1584	46483	1282	32113	892
30 Days	69000	1917	66000	1833	61800	1717
	65000	1806	64200	1783	54200	1505
	59800	1661	50400	1400	43000	1194
mean	64600	1795	60200	1672	53000	1472
90 Days	97000	2694	43250	1201	37900	1035
	93000	2583	38000	1055	28250	785
	88000	2444	——	——	——	——
mean	92666	2574	40625	1128	33075	919

TABLE IV

TRANSVERSE STRENGTH OF BARS 6"x 6"x 18"

Age	Per Cent of Voids Filled with Mortar					
	125		100		75	
	Breaking Load		Breaking Load		Breaking Load	
	Total	Unit Stress Lbs. per sq. in.	Total	Unit Stress Lbs. per sq. in.	Total	Unit Stress Lbs. per sq. in.
7 Days	2780	347	1790	224	1750	219
	2520	315	1830	229	1550	194
mean	2650	332	1810	226	1650	206
30 Days	3980	498	4240	530	2170	271
	3800	475	3910	489	1860	232
mean	3890	486	4075	509	2015	252
90 Days	4820	602	5000	625	2000	250
	5050	631	4800	600	2500	312
mean	4935	617	4900	612	2250	281

TABLE V

COMPARISON OF RATIOS

Age	Per Cent of Voids Filled with Mortar		
	125	100	75
	Crushing Strength		
7 Days	123 %	100%	69%
30 Days	107%	100%	68%
90 Days	228%	100%	81 %
mean	153%	100%	79%
	Transverse Strength		
7 Days	146%	100%	91 %
30 Days	95%	100%	49%
90 Days	101 %	100%	46%
mean	115 %	100%	62 %

TABLE VI

COMPARISON OF COST

Material	Price	Per Cent of Voids Filled with Mortar					
		125		100		75	
		Amount	Cost	Amount	Cost	Amount	Cost
Stone	$1.50 per cu. yd.	.94 cu. yd.	$1.41	.97 cu. yd.	$1.46	.99 cu. yd.	$1.48
Sand	.75 per cu. yd.	.44 cu. yd.	.33	.35 cu. yd.	.26	.26 cu. yd.	.20
Cement	3.00 per bbl.	.86 bbl.	2.58	.69 bbl.	2.07	.52 bbl	1.56
Total Cost			$4.31		$3.79		$3.24
Relative Cost			114%		100%		86%

CONCLUSION.

By an examination of table II it is seen that an increase of 25 per cent in the amount of mortar, increases the crushing strength 53 per cent, and the transverse strength 15 per cent, or an average increase in strength of 34 per cent. With a corresponding decrease of 25 per cent in the amount of mortar, there is a decrease of 21 per cent in the crushing strength, and of 38 per cent in the transverse strength, or an average decrease in strength of 30 per cent. From these results it is seen that the strength of concrete varies more rapidly than the per cent of the voids filled. The maximum strength would probably be obtained when the concrete contains no voids, and is a perfectly uniform and solid mass.

In Baker's "Treatise on Masonry

Construction", it is shown that when an amount of mortar equal to 100 per cent of the voids is used, the voids are not entirely filled, as each stone becomes covered with a thin layer of mortar, thus forcing them apart, and increasing the amount of voids. To entirely fill the voids, an amount of mortar equal approximately to 140 per cent of the voids is necessary.

In computing the cost of these concretes no allowance was made for the cost of labor; but as this would be nearly the same for all, the omission would not affect the relative cost.

According to Table VI, the concrete which has an amount of mortar equal to 125 per cent of the voids is the most economical of those investigated; since for an increase in cost of 14 per cent, there is an increase in strength of 34 per cent, while for a decrease in cost of 14 per cent, there is

a decrease in strength of 3.0 per cent.

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